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Sustained Reduction of Microbial Burden on Common Hospital Surfaces Through The Introduction of Copper

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ABSTRACT

Background: The contribution of environmental surface contamination with pathogenic organisms to the development of healthcare-associated infections (HAI) has not been well defined.

Methods: The microbial burden (MB) associated with commonly touched surfaces in intensive care units (ICUs) was determined by sampling six objects in 16 rooms from ICUs in three hospitals over 43 months. At month 23, copper-alloy surfaces, with inherent antimicrobial properties, were installed onto six monitored objects in 8 of 16 rooms and the effect that this application had on the intrinsic MB present on the six objects was assessed. Census continued in rooms with and without copper for an additional 21 months.

Results: In concert with routine infection control practices, the average MB found for the six objects assessed in the clinical environment during the pre-intervention phase was 28 times higher (6,985 cfu/100 cm^2, n=3977 objects sampled) than levels proposed as benign immediately after terminal cleaning, <250 cfu/100cm^2. During the intervention phase the MB was found to be significantly lower for both the control and copper surfaced objects. Copper was found to exert a significant 83% reduction to the average MB found on the objects (465 cfu/100cm^2, n=2714 objects) as compared to the controls (2,674 cfu/100cm^2, n=2,831 objects, $p<0.0001$).

Conclusion: The introduction of copper surfaces to objects formerly covered with plastic, wood, stainless steel and other materials found in the patient care environment significantly reduced the overall MB on a continuous basis thereby providing a potentially safer environment for hospital patients, HCWs and visitors.

Introduction

Despite best efforts promoting infection control protocols (28, 33), hospital-acquired infections (HAI) remain a common complication of hospital care occurring at an estimated rate of two-million annually in the US (30). At issue is the source of the microbes responsible for HAI. Much work has focused on the transfer of microbes from patients to healthcare workers (HCWs) and vice versa, and it is likely that commonly touched items serve as significant reservoirs for these microbes.

Microbes have an inherent ability to colonize any surface. Studies have shown that microbes can persist for weeks on stainless steel surfaces and polymeric materials used to fabricate touch surfaces in hospitals (22). MRSA may exist on surfaces for as long as 360 days (37, 38) and spore-forming bacteria, including *Clostridium difficile* can survive for months. The longer a nosocomial pathogen persists on a surface, the longer it may be a source for transmission to a susceptible patient or HCW (5, 13, 17, 21, 26, 29). Frequently touched surfaces such as doorknobs, push plates, bed rails, faucet handles, and IV poles, have been identified as reservoirs for the spread of pathogenic microbes (3, 27) which can easily contaminate hands and equipment of HCWs who, in turn, can transmit these pathogens to patients during routine care.

A concentration of less than 250 aerobic colony-forming units (cfu) per 100 cm^2 of surface area has been proposed as a standard for being considered benign immediately after terminal cleaning (11, 19). When the Microbial Burden (MB) exceeds this level transmission likely increases from the surfaces to healthcare workers and/or patients. To date, while there are multiple protocols for hand-hygiene and room cleaning, there are few strategies that can consistently minimize the MB found in the environment. CDC guidelines *for Disinfection and Sterilization of Healthcare Facilities* (28), describe reducing rates of HAI through appropriate use of disinfection and sterilization of the patient care environment. These guidelines incorporate a disinfection strategy devised more than 40 years ago (34) on the predicted degree of risk involved in the use of inanimate objects: *critical,* which includes items that enter sterile tissue (surgical instruments); *semi-critical,* which includes items that come into contact with mucous membranes or non-intact skin (endoscopes); and *non-critical,* which includes items that only come in contact with skin. Environmental surfaces fall within the non-critical category (16, 31, 34). Increasing evidence suggests that enhanced cleaning/disinfection of environmental surfaces can reduce contamination of HCWs and thus reduce transmission of hospital pathogens (4). However, numerous reports indicate that a high percentage of environmental surfaces are not terminally cleaned well (7-9). When objects from hospital rooms were cultured, 94% of those from rooms housing VRE infected patients and 100% from those housing *C. difficile* patients were widely contaminated with the organisms (12).

In vitro (24, 25, 39) and *in vivo* (10, 15, 20) studies have established the effectiveness of metallic copper surfaces as an antimicrobial material for its ability to reduce the concentration of bacteria on hard surfaces. In this study we have expanded on these observations by characterizing the MB associated with commonly touched objects surfaced with and without copper in the intensive care unit (ICU) in order to understand the risk that the MB might represent and the benefit that a perpetually active copper material might offer in continuously reducing the MB in the built hospital environment.

MATERIALS AND METHODS

SETTING: A multi-site study was conducted within the ICUs of three separate US hospitals. The study was approved by the institutional review boards for all sites as well as by the Office of Risk Protection of the United States Army, the sponsor of the work. The Medical University of South Carolina (hospital 1) located in Charleston, South Carolina is a 660-bed academic facility with 17 medical ICU beds. Memorial Sloan Kettering Cancer Center (hospital 2) located in New York, New York is a 432-bed cancer hospital with 20 medical-surgical ICU beds. The Ralph H. Johnson Veterans Administration Medical Center (hospital 3), also in Charleston, is a 98-bed hospital with eight medical ICU beds.

STUDY DESIGN: The MB associated with six common, high touch objects with which patients, HCWs, and visitors routinely interact between daily routine cleanings (Table 1) were measured weekly for 43 months using six rooms each from hospitals 1 & 2 and four rooms from hospital 3 for a total of 16 rooms. Commencing during month 23 (intervention phase) the six objects associated with one-half of the study rooms were surfaced with a continuously active antimicrobial material, metallic copper, in order to determine the effect on the MB.

FABRICATION OF ITEMS SURFACED WITH COPPER ALLOYS: The objects surfaced with copper were fabricated using copper alloys registered with the U.S. EPA for their inherent ability to kill bacteria (36). Four items were common to all hospitals; the side rails of the patient bed, the over-bed tray table, the IV pole, and the contact surface of the arm rests of the visitor's chair (Figure 1). Two other high touch objects were also sampled from each site (Table 1). For additional details on fabrication please see the supplemental material.

ENVIRONMENTAL CLEANING REGIMES: Each of the study sites followed routine standards of environmental cleaning and disinfection as prescribed by their respective infection control programs. This required that all objects and surfaces be cleaned at least once each day using a prescribed hospital grade disinfectant and upon patient discharge. Three US-EPA registered disinfectants were used during the intervention. Virex256® was used for routine and terminal cleaning. Dispatch® was used to clean rooms with a confirmed case of *Clostridium difficile* and Cavicide® was used for spot cleaning. Additionally, during the pre-intervention phase one site, Hospital 2, used the disinfectant ElimstaphNo2® (Walter G. Legge Company, Inc., Peekskill, NY) rather than Virex256® for its routine and terminal cleaning. The products were all used according to the label instructions and were consistently applied."

SAMPLE COLLECTION PROCEDURE: Surfaces were sampled once each week at approximately 9 AM, excluding weeks with US federal holidays using either a 10 cm x 10 cm or 4 cm x 25 cm sterile template placed over each surface. The exposed area was vigorously wiped using uniform pressure and motion, five strokes horizontally and vertically for a total of ten strokes in each direction. Samples were transported to Medical University of South Carolina and processed as previously described (1). MB was reported as colony forming units (cfu) per 100cm^2. For greater detail see supplemental materials and methods.

CALCULATIONS AND STATISTICAL ANALYSIS: The average MB of each item was calculated and the MB of each room was determined as the sum of the MB of the six objects within that room. The Kruskal-Wallis Test was used to compare the average MB associated with objects and rooms (EpiInfo, CDC, Atlanta GA) between pre-intervention and intervention phases as well between copper surfaced rooms and control-surfaced rooms. A p-value of ≤ 0.05 was considered statistically significant. The antimicrobial efficacy of copper was calculated as the difference in average MB between copper and non-copper objects and rooms and was expressed as the percentage with which copper reduced the MB.

RESULTS

INTRINSIC MICROBIAL BURDEN FOUND ON COMMON HIGH TOUCH OBJECTS

Over the 43 months of the study, samples were recovered from 9,522 objects in 1,587 rooms across three study sites. The average MB found for the six objects assessed in the clinical environment during the pre-intervention phase was 28 times higher (6,985 cfu/100 cm^2, n=3977 objects sampled) than levels commonly accepted as benign, <250 cfu/100cm^2 (Figure 2) (11, 18, 19, 23, 40). This value was exceeded for each object sampled. Bed rails were the most heavily burdened of the objects averaging a concentration 69 times greater than the level proposed as benign immediately after terminal cleaning or 17,336 cfu/100cm^2 with a standard error of sampling of ± 2,896 cfu/100cm^2 (For additional detail please see Supplemental, Table S1). The majority of microorganisms (64%) were staphylococci where approximately 90% of the population recovered was coagulase-negative.

MRSA and VRE were also frequently recovered from objects. Bed rails had an average concentration of 151 cfu of MRSA/100cm^2 and of 667 VRE/100cm^2 and nurses call buttons had averages of 146 cfu of MRSA/100cm^2 and 16 cfu of VRE/100cm^2 (Figure 2). The average concentration of gram-negative bacteria on bed rails and call buttons was 57 and 109 cfu/100cm^2 respectively and the average concentration of gram-negative bacteria resident on the monitor and tray table was higher at 5,914 and 8,572 cfu/100cm^2 respectively, reflecting a small number of outliers from samples collected from hospital 2.

Copper Lowered the MB Found on Common High touch Objects

During the 21 month intervention the antimicrobial effect exerted by metallic copper surfaces was immediate and consistently evident. A significant, 83% reduction to the average MB recovered from the copper surfaced objects was seen. Collectively, the average MB likely to be encountered from one of the six copper surfaced objects was 465 cfu/100cm^2, n=2714 objects, while the average burden recovered from the control items was 2,674 cfu/100cm^2, n=2,831 objects ($p<0.0001$). The summative average for the six objects surfaced in copper was also approximately 83% lower, than the burden recovered from the control objects (2,521 vs. 14,813 cfu/100cm^2 (Supplemental, Table S2)). When considered individually, 5 of the 6 objects surfaced in copper also saw significantly lower burdens (Figure 3, Panel A, Supplemental Table S2). Polypropylene bed rails were again the most heavily burdened of the control objects sampled with an average MB of 6,456 cfu/100cm^2. In contrast, the MB recovered from copper bed rails was 94% lower (366 cfu/100cm^2) and this difference was significant (p<0.0001). Finally, the antimicrobial activity of copper was found to be universal in its ability to kill many types of microbes (Figure 3, Panels B &C).

Copper surfaces were also found to attenuate the inherent variability associated with the MB resident on surfaces within the patient care areas. Eighty-three percent of samples recovered from copper bed rails were found below 250 cfu/100cm^2 whereas only 20% of the samples recovered from the plastic rails were found below this level (Figure 4) suggesting that copper might limit the heterogeneity of risk to the patient attributed to the variation to MB by limiting the range of MB resident on commonly touched surfaces. The dynamic nature of the MB resident on the objects sampled, attributed to stochastic processes, was evident throughout the trial (Supplemental Figures S1 & S2). A comparison of the summative MB from the pre-intervention and intervention phases found that the MB was 64.4% lower during the intervention period of the trial (41,586 cfu/100 cm^2, n=668 rooms, vs. 16,188 cfu/100 cm^2, n=511 rooms; p<0.0001).

Effect of Copper Intervention on Antibiotic-Resistant Bacteria

When considering the frequency with which MRSA and/or VRE were encountered over the study period, 169 (2.4%) of 7,005 control objects were found to harbor MRSA, while 239 (3.4%) were found to harbor VRE. During the intervention phase, MRSA and VRE were recovered with greater frequency from objects in rooms without copper surfaces. MRSA was recovered eight times (0.3%; n=2,781 copper objects) compared to 19 times (0.63%; n=3,004; p=0.0804, control) while VRE was recovered 9 times from rooms with copper surfaces (0.3%) compared to 91 times (3%) from control rooms (p<0.0001). On a per sample basis, copper surfaces were approximately six-times less likely to harbor one of these organisms. Based on the summative MB measured for each of the surfaces sampled over the intervention period, the combined MRSA and VRE burdens were 96.8% lower on copper surfaces than on comparable plastic, wood, metal and painted surfaces and were 98.8%, less on the bed rails, the most heavily burdened object.

DISCUSSION

This study suggests that six common high-touch objects with which HCWs, patients and visitors routinely interact carry a substantial MB, and thus present a risk to patients. These data underscore the need to insure that cleaning is completed in an effective manner as bacterial concentrations resident on items sampled were well above values recommended immediately after terminal cleaning (11, 18, 19, 23, 40). Concentrations of bacteria on objects varied substantially (Figure 4). The stochastic behavior of the MB distributed across the three ICUs is likely attributed to the inherent dynamics of patient care, cleaning, patient characteristics as well as other unknown factors.

Incorporation of inherently and continuously active antimicrobial copper onto high-touch surfaces in the ICU offered an enhanced effect in combination with regular cleaning and infection control practices resulting in significantly lower MB and potentially safer surfaces. Bed rails were the most heavily burdened control objects with a maximum MB of 306,000 cfu/100 cm^2, seventeen times higher than the maximum value observed from a copper surfaced rail. In fact 80% of plastic bed rails had bacterial concentrations above the risk threshold for transferring infectious bacteria (Figure 4). In contrast, 83% of copper bed rails had levels below this threshold. Thus, generally, during the conduct of patient care, objects surfaced with copper carried concentrations of bacteria at or below the threshold recommended immediately after terminal cleaning (11, 18, 19, 23, 40). The antimicrobial activity of the metallic copper surfaces was equivalent throughout the course of the trial. This was evident from the observation that over the course of sampling, 46% of copper bedrails had no recoverable bacteria (Figure 4). In contrast only 3% of bed rails sampled from control rooms failed to yield viable bacteria.

Similarly, the five other copper items had remarkably lower burdens. The call button was the most heavily burdened of the copper-surfaced objects evaluated, however 71% of the samples were below the proposed terminal cleaning threshold. Seventy-five percent of chair arms sampled; 90% of tray tables; 91% of IV poles and 90% of data input devices were below the proposed standard of <250 cfu/100cm^2. In total, 45% of control objects from the 511 rooms sampled exceeded an average MB considered to represent a risk to patients, compared to just 16% of copper-clad objects. The most surprising finding was the 64% decrease in MB between the pre-intervention and intervention phases in the control rooms. This might be accounted for as a consequence of a number of independent and uncontrolled variables: First, the presence of copper on the unit may have resulted in better cleaning by the environmental services staff; 2) the presence of copper may have resulted in an antimicrobial halo limiting the transfer of microbes between control rooms as staff were common to both rooms; 3) or variations in compliance with other infection control measures such as hand hygiene might account for the differences seen.

Unlike programs for better compliance with infection control such as hand-hygiene or barrier precautions, the antimicrobial activity of copper-surfaced objects was not dependent on additional training or supervision. It did not require alterations to existing cleaning practices or add to the annual environmental cleaning costs, as does the application of ultraviolet light and/or hydrogen peroxide vapor deposition for reduction in MB. Additionally reductions to the MB manifested by the copper objects during active patient care approached the reduction level of 99.9% observed in tests conducted for registration of copper-based surfaces with the U.S. EPA.

Recent literature provides increased evidence that contaminated hospital surfaces may be a source of transmission of pathogens. Kramer reported that, in hospitals, surfaces with hand contact are often contaminated with nosocomial pathogens and may serve as vectors for cross transmission (17).

Steifeland found that in patient rooms with MRSA carriers, HCWs are just as likely to contaminate their hands or gloves from commonly-touched environmental surfaces as from direct contact with colonized patients (35). Boyce and colleagues (6) demonstrated that nurses frequently acquired MRSA on their gloves after touching surfaces near colonized patients and a report by Bhalla and others found that 53% of hand-imprint cultures were positive for one or more pathogens after contact with surfaces near hospitalized patients (2). Other studies have found that patients treated in rooms previously occupied by individuals with colonization or infection with MRSA, VRE, and C. *difficile* are at a higher risk of acquiring the organism than patients admitted to rooms where the previous occupant did not have colonization or infection (14, 32).

The use of copper to control or reduce the MB on surfaces in healthcare has been previously reported (10, 15, 20). In a South African community healthcare facility, copper surfaces (desks, trolleys) were associated with a 71% reduction in MB compared to control surfaces when sampled every 6 weeks for a period of 6 months (20). A recent crossover study in a 19 bed acute medical ward found that many copper surfaces were associated with significantly decreased MB compared to control surfaces when sampled weekly for 24 weeks with reductions ranging from -0.4 cfu/cm^2 to -80.3 cfu/cm^2 (15). Also, like our study, copper surfaces were significantly less likely to be contaminated with indicator organisms such as VRE and coliforms. Our study differs from these in several respects. Sampling in our study was performed over a substantially longer period of time (21 months), the objects surfaced with copper were often medical devices within close proximity to the patient and used routinely during direct patient care. Additionally, the populations cared for in the rooms involved in our study were critically ill and generally not ambulatory which reduced the influence of their interactions with other environmental surfaces within and outside the room.

Reducing the overall MB on a continuous basis, as evidenced in this study and others with the introduction of continuously active antimicrobial copper surfaces, may provide a safer environment for hospital patients, HCWs and visitors.

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Table 1

Antimicrobial Copper Alloys Used to Surface or Fabricate High Touched Items

	Copper Alloy	**Component Fabricated**	**Description**	**% Copper Content**
IV stands	C710 and C706 C693 C87610 C706 C706	Pole(s) IV hanger loops Base Handle Brackets	Copper Nickel Brass Silicon bronze Copper nickel Copper nickel	80% / 90% 75% 90% 90% 90%
Patient bed—Side rails	C110	Top of rails	Copper	99.99%
Over-bed table	C706 C110 C464	Table top Table bottom Release lever	Copper nickel Copper Naval brass	90% 99.9% 60%
Visitors' chair (arms)	C706	Arm rests	Copper nickel	90%
Nurse call button Computer Mouse	C638 C260 C260	Buttons Clamshell (Hospitals 1&3) Computer mouse (Hospital 2 Only)	Aluminum bronze Cartridge brass Cartridge brass	80% 80% 70%
Data Input devices	C524 C710	Base of Monitor bezel (Hospitals 1 & 2) Laptop palm rest (Hospital 3 Only)	Phosphor- Bronze Copper nickel	90% 80%

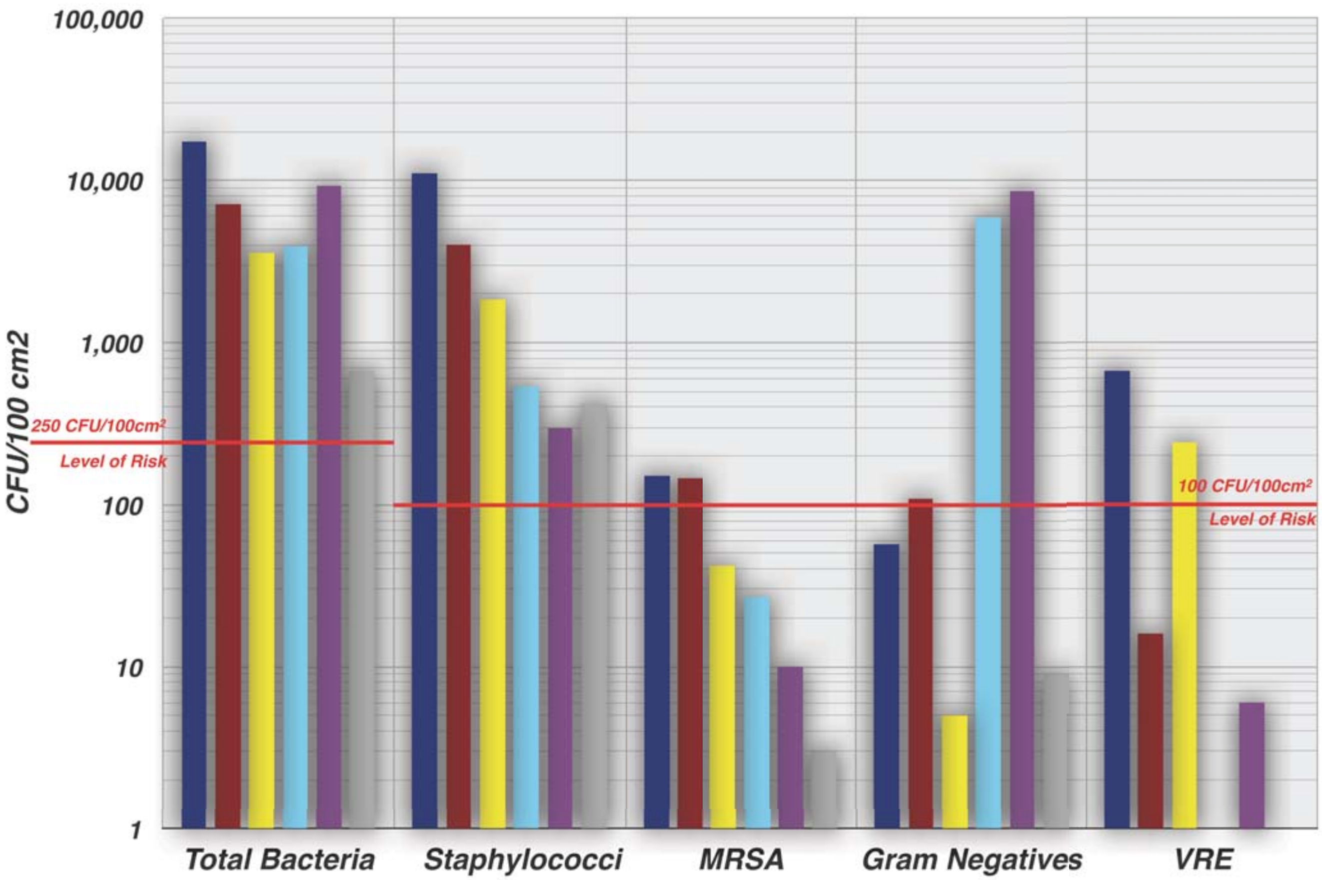
Figure Legends

Figure 1. Representative high touch objects and their respective placement in the ICU.

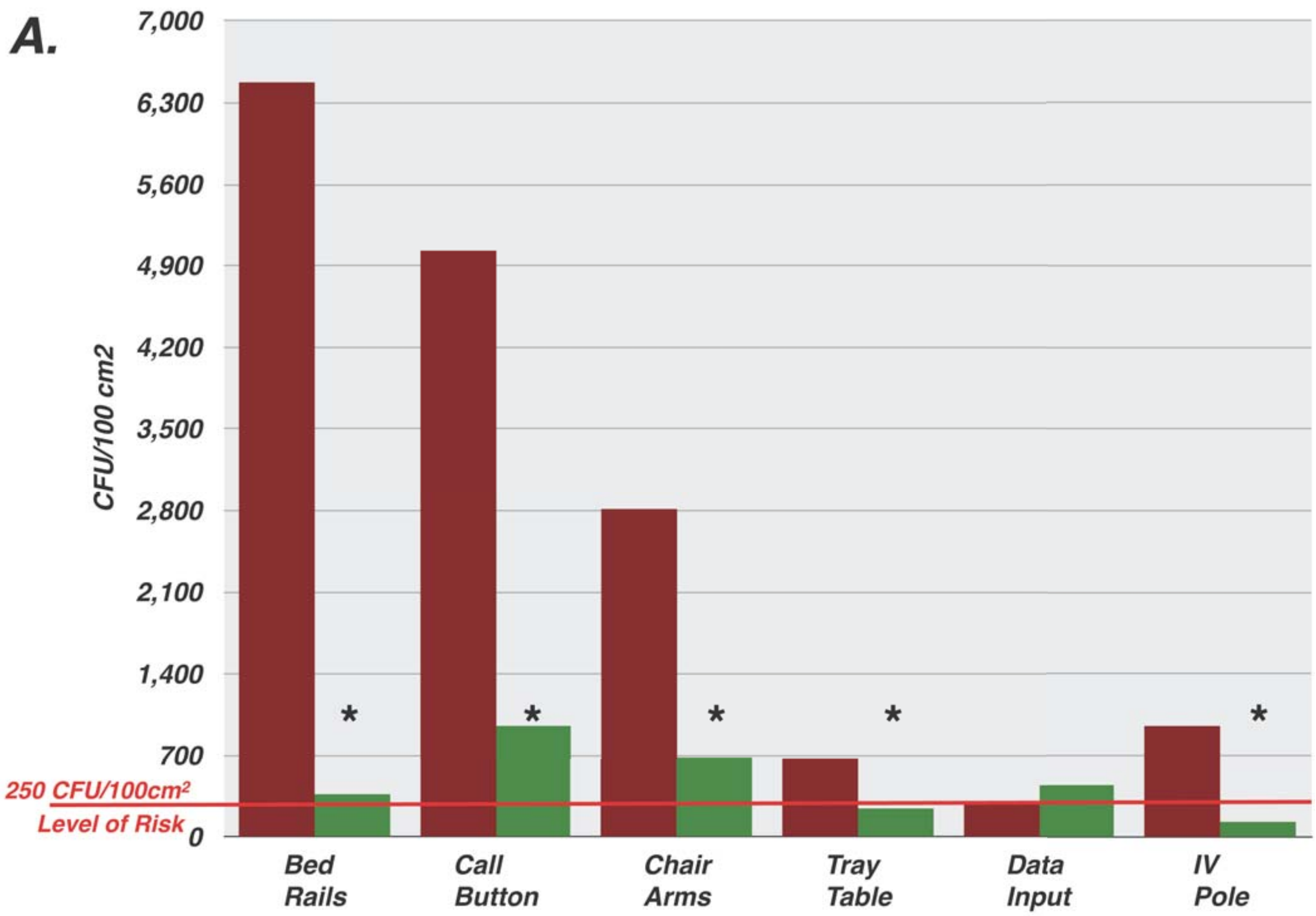
FIGURE 2. Assessment of the Inherent Microbial Burden Associated with High Touch Objects. The average concentration of bacteria, described by type was determined from samples collected from six inanimate objects for a period of 23 months (N=668 rooms). Bed rails, Dark blue bars; Call buttons (Hospitals 1 & 3 and Mice (Hospital 2), Red Bars; Arms of the Chair, Yellow Bar; Tray Table, Light Blue Bar; Data Input Device (Base of Monitor Bezel Hospitals 1 & 2 and Palm rest of laptop computer, Hospital 3), Purple; and IV Pole Grey Bars, (the call button represents values obtained from call buttons at 2 sites and a computer mouse from the third due to the absence of a call button

Figure 3. COPPER LOWERED THE MB FOUND ON COMMON HIGH TOUCH OBJECTS. Panel A. Comparison of the average MB between rooms with (Green Bars, N=501 rooms) and without (Red Bars, N=511 rooms) copper surfaced items**.** Samples were collected period of 21 months, processed and statistically analyzed as described in the methods (*denotes a p value <0.05). **Panels B (Non-Copper Objects) and C, (Copper Objects)** described the average concentration of bacteria, by type, recovered from Bed rails, (Dark blue bars); Call buttons (Hospitals 1&3 and Mice (Hospital 2), (Red Bars); Arms of the Chair, (Yellow Bars); Tray Table, (Light Blue Bar); Data Input Device (Base of Monitor Bezel Hospitals 1 & 2 and Palm rest of laptop computer, Hospital 3), Purple Bar); and IV Pole (Grey Bars), (the call button represents values obtained from call buttons at 2 sites and a computer mouse from the third due to the absence of a call button at that location).

Figure 4. Frequency distribution of the MB resident on all objects, by type, during the intervention. The MB observed for each sample from rooms with copper surfaced objects are described on the left, those without copper surfaced objects are described on right. The concentration of bacteria observed for each sample was placed into one of three categories, 0 cfu/100cm^2 (green bar), 1-250 cfu/100cm^2 (yellow bar), >250 cfu/100cm^2 (red bar) the final percentage, rounded to the nearest whole number, of each category was determined.

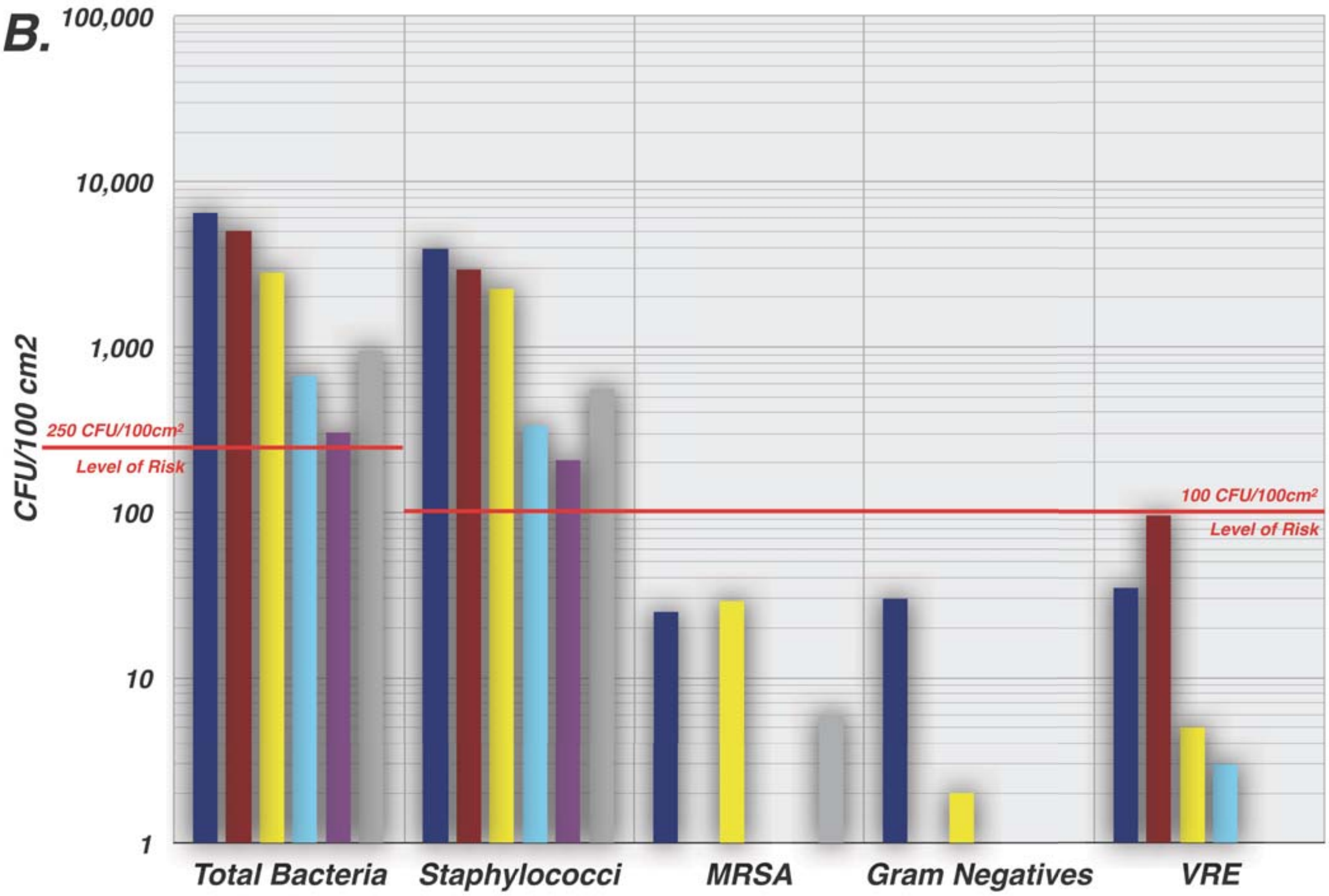


100,000
10,000
1,000
100
10
1
CFU/100 cm2
250 CFU/100cm²
Level of Risk
100 CFU/100cm²
Level of Risk
Total Bacteria
Staphylococci
MRSA
Gram Negatives
VRE

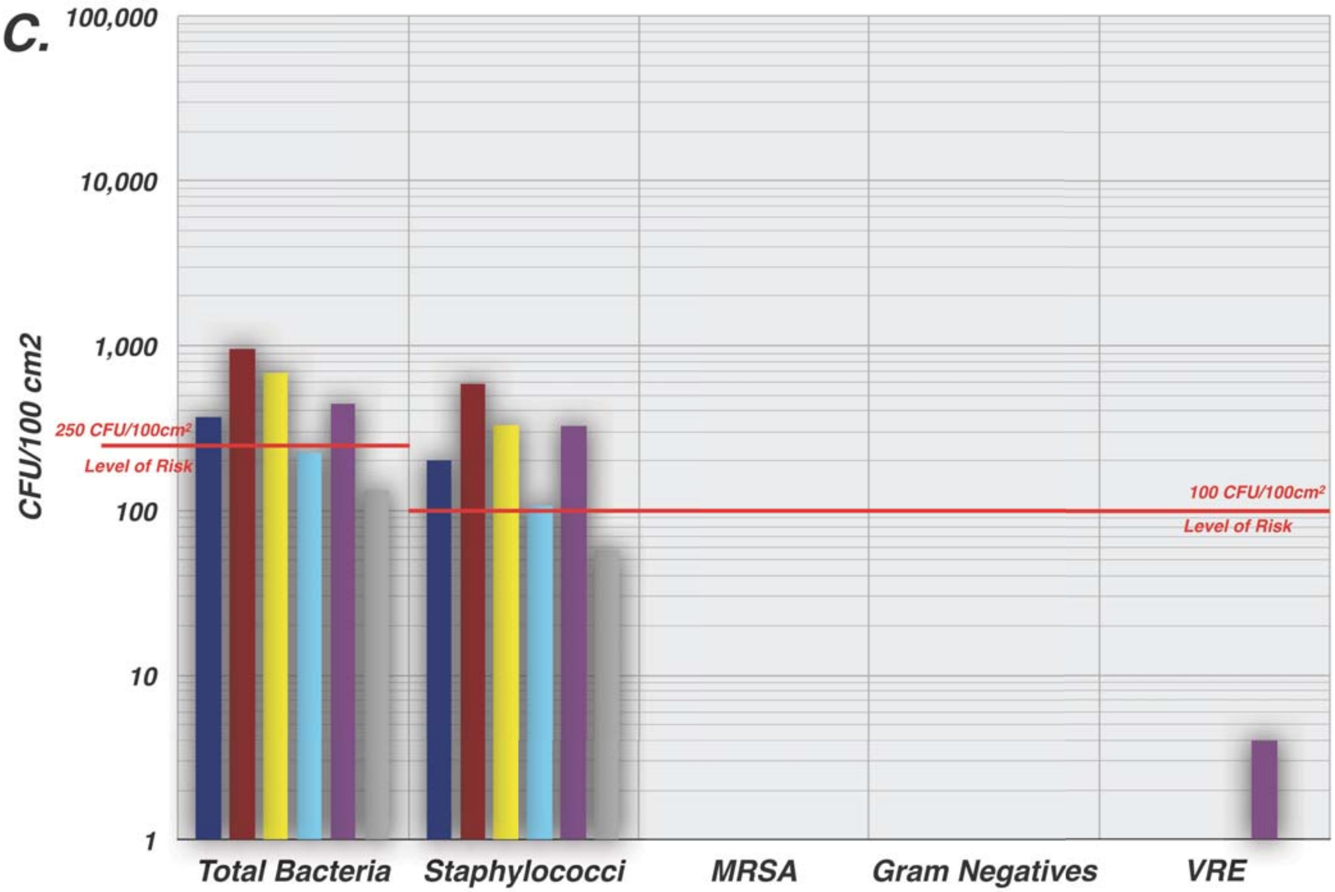


A.
7,000
6,300
5,600
4,900
4,200
3,500
2,800
2,100
1,400
700
0
CFU/100 cm2
250 CFU/100cm²
Level of Risk
*
Bed Rails
Call Button
Chair Arms
Tray Table
Data Input
IV Pole

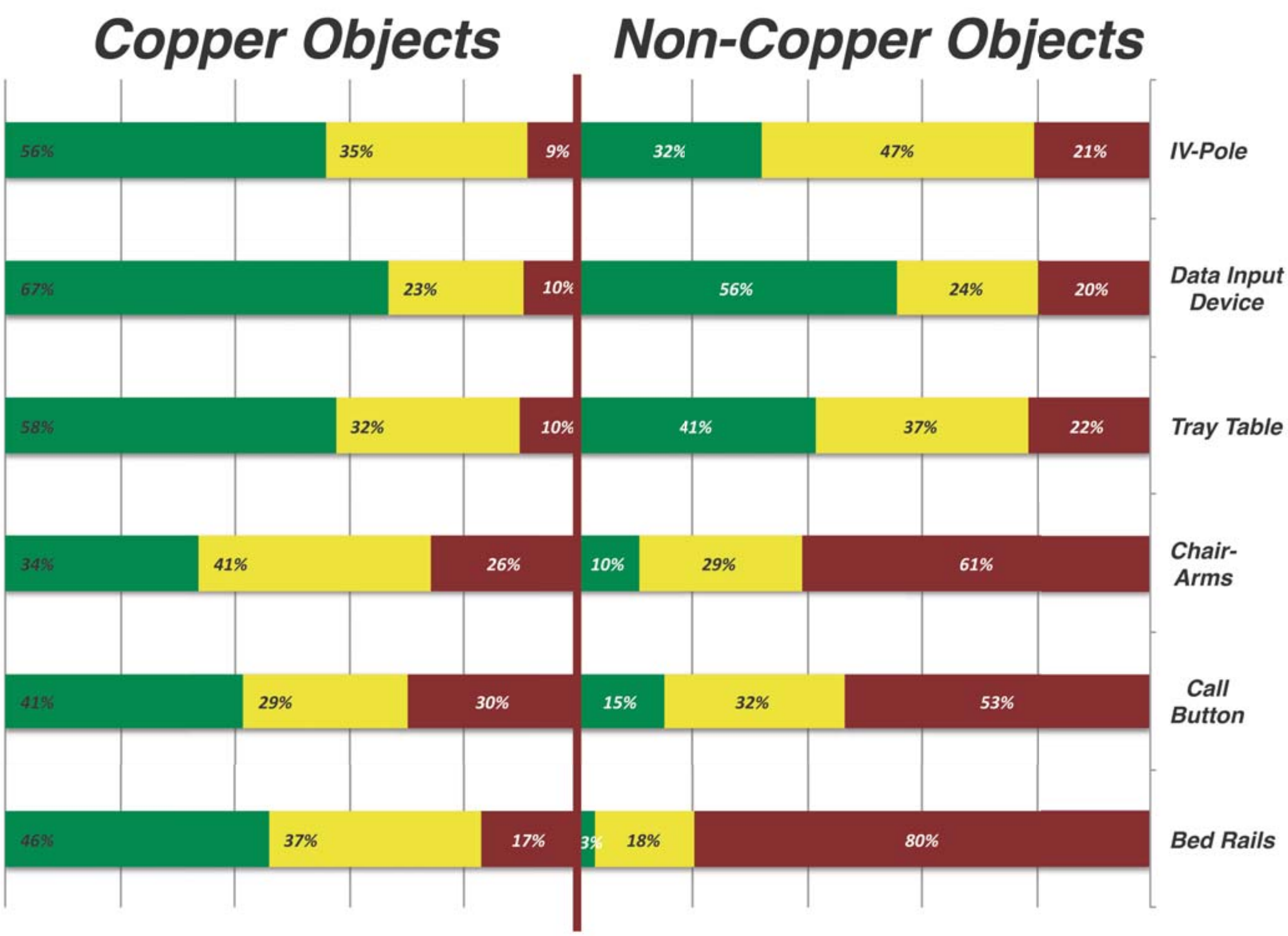
B.


100,000
10,000
1,000
100
10
1
CFU/100 cm2
250 CFU/100cm²
Level of Risk
100 CFU/100cm²
Level of Risk
Total Bacteria
Staphylococci
MRSA
Gram Negatives
VRE

C.



100,000
10,000
1,000
100
10
1
CFU/100 cm2
250 CFU/100cm²
Level of Risk
100 CFU/100cm²
Level of Risk
Total Bacteria
Staphylococci
MRSA
Gram Negatives
VRE


Copper Objects
Non-Copper Objects
56%
35%
9%
32%
47%
21%
IV-Pole
67%
23%
10%
56%
24%
20%
Data Input Device
58%
32%
10%
41%
37%
22%
Tray Table
34%
41%
26%
10%
29%
61%
Chair-Arms
41%
29%
30%
15%
32%
53%
Call Button
46%
37%
17%
3%
18%
80%
Bed Rails